# Compact Disk Media Evaluation

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When the Planetary Data System adopted CD-ROM as the primary media for archival data products, it did so with the expectation that CD-ROM would be both standardized (readable on any platform, unlike other optical media) and permanent, (capable of maintaining all data error-free for several decades). At some point the availability of hardware becomes questionable, but is assuaged by the proliferation of readers and the ability to 'archive' a reader system cheaply. I have a 'fantasy-plan' to celebrate the completion of the first stage of planetary data restoration in 1995 by producing a time-capsule. It would consist of a complete set of CDs (by then 500 to 1000 disks), stored in 10 hermetically sealed coffee cans along with a solar-powered PC and CD-reader. I would bet that such a time-capsule could be opened up in 1,000 years and the disks played back error-free.

This fantasy has been questioned recently. Articles in the Wall Street Journal and other periodicals have questioned the longevity of CD media. One explicitly predicted a 5-year maximum life due to oxidation of the metal reflective layer on CD-ROM disks. Such assertions have spurred both CD-ROM manufacturers and users to provide proof of longevity expectations. These efforts include a media life study by 3M Corporation; the formation of a longevity evaluation group of SIGCAT (Federal Special Interest Group for CD-ROM Applications and Technology); and the development of a strict quality control specification for CD-ROM production by government and industry representatives. PDS and the Data Distribution Lab have actively participated in these efforts.

## Plain Talk: CD-ROM Lifetime

3M Corporation has carried out extensive tests of its own CD-ROMs and disks from other vendors. Their conclusion is that the life expectancy of disks from different manufacturers varies markedly. This is something we learned by experience many years ago, and have carefully limited our vendor list to those companies which are known to produce top-quality CD-ROMs. This is nothing new, we faced a similar problem in the 1970's buying 50,000 magnetic tapes for the Viking Project. Several thousand '100 percent certified-error free' tapes were rejected before the vendor realized our commitment to quality.

A second conclusion of the study is that 3M CD-ROMs have a life expectancy of at least 100 years. This projection is based on a strict block-error rate standards

(50 Vs an allowed maximum of 220 in the industry CD-ROM specification). If the industry standard rate is used, the projected life of a disk is on the order of 900 years. 3M explicitly guarantees their disks for 25 years, and will replace any disks which deteriorate within that period of time. They keep two copies of each user disk in a vault, which are used for reorders and could be used to implement the guarantee. Such a guarantee, from a formidable US vendor of data storage media, provides strong assurance of the archival nature of CD media.

CD-LEGG and CD-RIM.

The Federal Special Interest Group for CD-ROM Applications and Technology (SIGCAT) has two sub-groups which are involved in CD media analysis. The CD-ROM Longevity Evaluation Government Group (CD-LEGG) has been formed with representatives from the National Technical Information Service (NTIS), National Institute of Standards and Technology (NIST), United States Geological Survey (USGS), NASA/JPL, the Library of Congress, the National Archives and the Department of Defense. The initial focus of this group has been to understand the factors which determine the archival characteristics of CD-ROM media. The first meeting at NTIS discussed CD-ROM quality parameters and summarized the initial testing done by the NTIS on samples of disks from all agencies and vendors. Figure 1 illustrates a major problem in CD-ROM testing. It shows the block error plots from two disks as measured on two testing devices, the Design Science CD Analyzer and the CD-CATS tester. There is no visible correlation between the plots from the different devices, although the machines provide consistent overall statistics. Part of the problem is that a single fingerprint or even a mote of dust can influence the results. A second meeting at the National Archives discussed 3M's longevity testing and developed a proposal to be forwarded to the National Archives requesting a formal study of CD-ROM media by the National Institute of Standards and Technology. A similar study has just been completed on write-once optical media (see references). It examines the methodology of media life testing and provides some interesting conclusions. One is that the media life on the inside of a WORM disk may be hundreds of years but on the outside only 10 or so. CD-RIM (Reliability and Integrity of Media) overlaps somewhat with CD-LEGG but has focused on the technical aspects of the media and on harsh-environment testing and ruggedization. Anyone interested in participating in SIGCAT or the special interest groups should contact Jerry McFaul, US Geological Survey, Reston, Va., 703-648-7126. The SIGCAT Info Line is 703-648-4452.

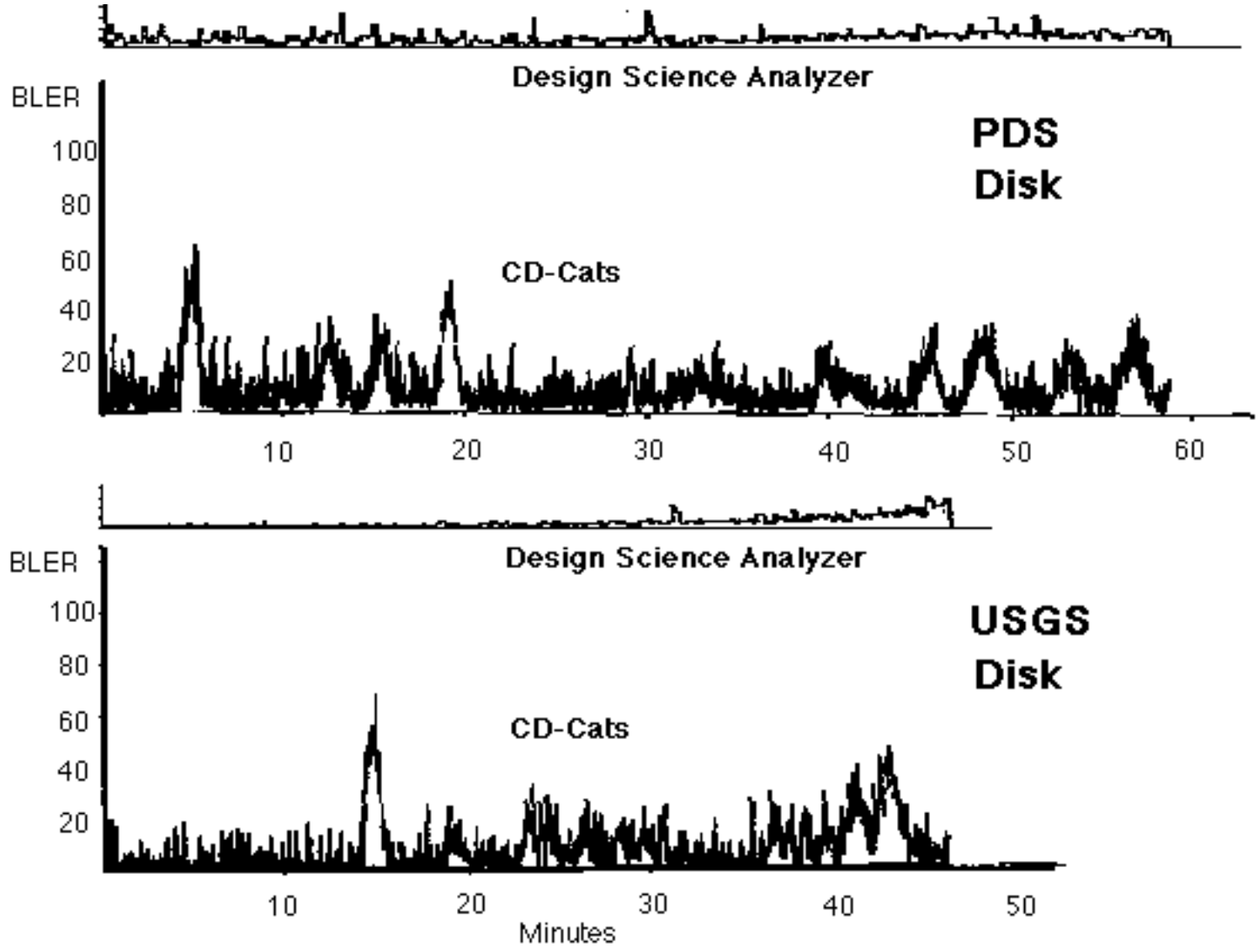


Figure 1. CD-ROM Block Error Plots

CD-ROM Quality Control Standard

The Information Handling Committee of the Intelligence Community Staff has commissioned a specification containing proposed standards for CD-ROM mastering. The standard defines stringent quality parameters and vendor testing procedures which should result in top quality CD-ROMs. The standard also provides an excellent tutorial on the characteristics of CD-ROM media and its quality parameters. Copies of the latest version of the document are available from the address given in the references.

CD Quality Overview.

The technology packaged in a $500 CD-ROM player is astounding. Consider that the laser beam must track a .6 micron-wide path of pits which weaves left and right up to 50 microns per rotation and may move vertically by as much as a millimeter at the outer edge of the disk. The disk rotation speed varies from 500 RPM on the inner tracks to 200 RPM outside to maintain a constant flow of data to the laser beam. A seek to a data file on disk involves checking the table of contents for a location, guessing at where on the disk to seek to, getting there and slowing down or speeding up to lock on the track, seeing if the block is near-by then homing in on position until the beginning block has been found. Despite all this work, seek times continue to drop, and new drives with access times as low as 280 ms are now being sold.

The signal recorded in the pits represents an Eight-to-Fourteen modulated code. Simply put this coding scheme assures that the pits occur frequently enough to allow them to be used for laser beam tracking. The data is encoded using Cross Interleaved Reed-Solomon Coding (CIRC). This process scrambles the data both in position and time. The cross coding breaks up the bytes in a message, for example 'hello' might become 'ohlel'). Interleaving scrambles the data in time ('you are my lucky star' might become 'you lucky are star my'). The effect of these two processes is to minimize the damage done by burst errors when reading the data back. This level of error correction is done by the hardware in the CD-ROM drive and provides an error rate of 10-12, or one potential error in 86 days of constant playback. If you are reading 1 megabyte files you might experience a data error once in every million files. An additional 'layered' CIRC error detection and correction scheme is available (using 276 bytes of each CD-ROM data frame), which can provide a 10-13 error rate if implemented in the reader. The high quality of CD-ROMs being manufactured today allows many vendors to ignore this error correction capability.

CD Test Results.

As part of its participation in SIGCAT activities, the Data Distribution Lab has submitted samples of two of the oldest CD-ROM disks in existence as well as samples of CD-Recordable media for testing by CD-LEGG. Tests were performed by the Naval Air Defense Center and the National Technical Information Service. Both of these groups are actively involved in CD production and testing. The CD-ROM disks submitted were 'semi-virgin' copies (stored in my office for the past 5 years) of a USGS Sampler disk produced by 3M in December 1986 and of the PDS Science Sampler Volume 1, produced by Sony in early 1987. The numeric test results are shown in Table 1. Also shown are industry specifications from documents which define CD technology (called the Red and Yellow Books); a tighter set of specifications proposed for federal CD-ROM procurements; test results for a recently manufactured CD-ROM; two samples of recordable CDs and

a Century Disk. The Century Disk is from Digipress and is made of glass with a gold reflective layer.

The basic indicator of CD-ROM quality is the average block error rate per second (BLER). All CD-ROMs have block errors, and the best rate that can be achieved by any vendor is about 2.5 errors per second. Most of the CD-ROMs which PDS has produced test out at about 5. The CD-ROM specifications (Red and Yellow books) call out 220 as the maximum allowable rate, but a more strict guideline of 50 is considered the highest rate that should be allowed on any CD-ROM.

Both older disks are well within industry specifications in nearly every test category. With respect to block error rate (BLER), the disks are better than many CDs being manufactured today. Vendors do not want to commit to average BLER less than 50, but these 5 year old disks show average values of 8 and 11. They exceed the write-once disks and even the Century disk in average BLER.

The early write-once disk shows error rates substantially higher than current mastered CD-ROMs. Newer versions of the media come closer to the specifications. A KODAK Photo-CD tested earlier this year showed an average BLER of 5.

The parameters which are outside the specification include scanning velocity and track pitch for the USGS disk and vertical deviation for the PDS disk. The first two parameters are determined by the mastering process and not a result of aging. The vertical deviation for the PDS disk is well within the industry standard, but just over the proposed guideline. All disks tested except the New CD-ROM exhibit E22 errors. These errors indicate that all the error correction capability of the built-in CIRC is being used to successfully read the disk. While this is not a good sign, there is still the layered ECC if any of these correctable errors become uncorrectable.

Figure 2 shows a statistical correlation of the parameters listed in Table 1. It was produced using Parameter Manager Plus on the Macintosh. The only significant correlation's appear to be inverse relationships between reflectivity and burst error length, and between push pull and radial noise.

Table 1. CD Test Results

| Test Parameters | Industry Standard | Proposed Guideline | PDS Disk | USGS Disk | New Disk | New CD-WO | Early CD-WO | Century Disk |
|---|---|---|---|---|---|---|---|---|
| Eccentricity (microns) | <70 | <50 | 28 | 17 | 27 | 31 | 38 | 25 |
| Reflectivity (percent) | >70 | >70 | 81 | 85 | 84 | 79 | 74 | 83 |
| Scanning velocity (m/s) | 1.2-1.4 | 1.2-1.4 | 1.24 | 1.13 | 1.39 | 1.40 | 1.21 | 1.39 |
| Track Pitch (microns) | 1.5-1.7 | 1.55-1.70 | 1.59 | 1.78 | 1.59 | 1.61 | 1.60 | 1.59 |
| Push pull | .040-.070 | .045-.075 | .052 | .048 | .056 | .092 | .085 | .044 |
| Asymmetry (percent) | +-20 | +-15 | 15 | 10 | -2 | 8 | -7 | -11 |
| Radial noise (nm) | <30 | <15 | 14 | 13 | 9 | 6 | 8 | 12 |
| Cross talk (percent) | <50 | <50 | 23 | 23 | 28 | 21 | 26 | 37 |
| Deviation (mm) | +-.50 | +-.20 | -.24 | .17 | -.16 | -.05 | -.14 | .06 |
| Block error rate (avg/max) | <220 | <50/100 | 11/65 | 8/68 | 2/17 | 10/32 | 48/100 | 31/74 |
| Maximum Burst error length | | 7 | 7 | 8 | 2 | 15 | 33 | 5 |
| E22 errors | | 0 | 59 | 51 | 0 | 10 | 54 | 8 |

Parameter definitions:

Eccentricity - Measures deviation of tracks from perfect centering about the hole in the disk.

Reflectivity - Measure of light returned by reflective layer of disk.

Scanning velocity- Speed at which the track moves by the laser beam.

Track pitch - Distance from one track to the next.

Push Pull - Measure of the horizontal variance of track position making it hard to track.

Asymmetry the - Measure of ratio of the shortest and longest pits and lands on disk.

Radial Noise - Measure of poorly defined pits or damaged tracks.

Cross talk - Measure of the track signal Vs the signal between tracks.

Deviation - Vertical deviation.

Block error rate - Measure of the number of blocks per second which have errors (either correctable or uncorrectable) at the first decoder.

Burst error length- Number of consecutive burst or cluster errors at the first decoder.

E22 errors - Number of two symbol correctable errors at the second decoder. Requires using all the built-in CICR error correction capability.

Conclusions.

Contrary to published reports, CD-ROM is probably the most durable and long-lived media in existence today. It will not self-destruct in a few years, but will continue to transport the fruits of our research endeavors to scientists of the future for tens, hundreds, or thousands of years. The real job is making sure

that the data we put on the plastic disks is well-documented and worthy of transfer to future generations. The Data Distribution Lab will continue to evaluate the longevity and characteristics of CD related media. We would appreciate hearing of any media problems encountered by CD users.

The PDS has distributed more than 35,000 CD-ROMs thus far with only one (unverified) complaint of an unreadable disk. Problems in reading CD-ROMs or CD-Recordable disks can often be overcome by using a lens cleaning disk. Some computer stores and most music outlets carry them. Every time my Apple CD-SC has refused to mount a disk, the lens cleaner has immediately solved the problem. Do not store disks in an environment where you would be uncomfortable. The paint shop and janitor's room are places where solvents abound, and they will attack polycarbonate.

Many claims have been made that one could drill a hole in a CD-ROM and still read the contents. I tried it with a give-away disk from a recent conference. The smallest bit I could find, (1/16 in) produced unrecoverable errors in one directory on the disk, which happened to hold a hypertext version of the Bible. Honest, I did it in the name of science!

Acknowledgments:

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References:

Proposed Standard For Controlling the Quality of CD-ROM Discs
CD-ROM Quality Control Standard, CD-QC,
Commissioned by The Information Handling Committee,
Director of Central Intelligence,
Intelligence Community Staff,
Washington, DC 20505.

Plain Talk: CD-ROM Lifetime.
3M Optical Recording.
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612-733-2142.

Development of a Testing Methodology to Predict Optical Disk Life

Expectancy Values
NIST Special Publication 500-200
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